Renewable and Sustainable Energy Reviews 22 (2013) 23–32

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Energy and greenhouse gas emissions review for Macao

J.S. Li [a], G.Q. Chen [a,b,*]

[a] State Key Laboratory of Turbulence and Complex Systems, College of Engineering, Peking University, Beijing 100871, China
[b] Nonlinear Analysis and Applied Mathematics, King Abdulaziz University, Jeddah, Saudi Arabia

ARTICLE INFO

Article history:
Received 31 July 2012
Received in revised form
23 November 2012
Accepted 26 November 2012
Available online 21 February 2013

Keywords:
Macao
Energy consumption
GHG emissions

ABSTRACT

Although Macao is one of the individual members of the Kyoto Protocol, a holistic picture to draw its energy consumption and GHG emissions has been lacking. A comprehensive review of energy consumption as well as GHG emissions is presented in this study for Macao since the handover of sovereignty to China. The results show that the Macao's energy consumption and its related GHG emissions were 32,700 Terajoules (Tj) and 3.70E+06 t CO_2 e. in 2010, increased by 31.10% and 100.34% over those of 2000, respectively. The results also indicate that electricity is the biggest contributor to GHG emissions, and induced a large amount of GHG emissions in other places. Energy intensity and per capita GHG emission also witnessed growth from 2000 to 2010. In terms of sectors of the economy, the service industry, commerce, restaurants and hotels, transportation and households are the leading four energy users and GHG emission inducers. Our analysis also suggests that decision-makers should take indirect emissions from energy consumption into consideration to support Macao's energy, climate and sustainability initiatives.

Contents

* Corresponding author.
E-mail address: gqchen@pku.edu.cn (G.Q. Chen).

1364-0321/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2012.11.072

1. Introduction

Cities are characterized by compact settlements and modern lifestyles [1]. As centers of population, manufacturing, commerce, construction and service industries, cities' prosperity and development demand large amounts of energy. International Energy Agency [2] estimated that cities account for 67% of energy consumption worldwide, a figure which is expected to rise, given that cities will host 60% of world's population by 2030. In China, cities are responsible for 75% of total energy consumption and 84% of commercial energy consumption [3]. As the trend of urbanization continues, cities are expected to consume more energy [4–6].

A price has to be paid, however, for the benefits of city life. People living in the cities have witnessed environmental degradation directly related to extensive consumption of energy, from major sources such as fossil fuels. Besides air pollutants which are harmful to people's health, urban energy consumption releases large amount of greenhouse gases (GHG) into atmosphere, which have significantly impacted global climate [7,8]. It is recognized that GHG emissions from cities dominate global anthropogenic GHG emissions, mainly driven by energy consumption [9,10]. According to The-Climate-Group [11], cities have already contributed 75% of the current global GHG emissions. Within China, cities emitted 85% of energy-related CO_2 emissions in 2006 [2]. As the rapid urbanization is still ongoing, energy and GHG emissions issues will continue to be the greatest challenges to cities' development and sustainability. Consequently, cities are assumed to take major responsibility for energy conservation and GHG emissions reduction. To achieve this goal, it is crucial to take actions to implement urban energy strategies and emission mitigation policies.

Considering the great importance of energy-related GHG emissions from cities, many efforts have been made in both political and academic fields to reduce cities' energy-related emissions. As cities become focal points for GHG mitigation, international organizations, such as Cities for Climate Change Protection, the C40 Cities Climate Leadership Group, ICLEI–Local Governments and the Climate Summit for Mayors, are seeking strategies which might promote both development and sustainability [12,13]. In addition, a number of researchers have already developed methodologies to calculate some cities' energy-related GHG emissions [3–6,9,14–24], which have helped policy makers to implement efficient energy policy to curb city's GHG emissions. However, because cities' characteristics and economic structures are so different from one to another, it is impossible that one specific city's energy and emission reduction strategies would be suitable in all situations [5]. In order to effectively guide one specific city's energy and GHG mitigation plans, a comprehensive study of this individual city's energy consumption and its related GHG emissions is needed.

Macao, one of the two special administrative regions of the People's Republic of China, is located in the Pearl River Delta, with an area of 29.7 km^2 and with a population of 544.6 thousand, as one of the most densely populated regions in the world [25]. The climate in Macao is typical humid subtropical, with a mean air temperature of 22.7 °C, average relative humidity between 75% and 90%, and average annual rainfall of 2120 mm [26]. Macao is one of the most important gaming centers across the world. With more than 400 years of development, the service industry such as gaming industry and the associated hospitality services have now become the backbone of Macao's economy. Benefitting from the boom in casinos, Macao has been experiencing spectacular economic growth since the handover of sovereignty to China on December 20th, 1999. Macao's gross domestic product (GDP) increased from 71.1 billion Patacas (MOP) in 2000 to 214.9 billion MOP in 2010 [25], equaling 33.5 billion US dollars and 75.0 billion US dollars, respectively. The annualized GDP per capita in Macao also increased from 20,568 US dollars in 2000 to 49,199 US dollars at the end of 2010 [25], which was even higher than that of Hong Kong [27]. The fast pace of Macao's economic growth resulted in a rapid increase in energy use (and thus GHG emissions). Although there have been several studies analyzing Macao's energy-related GHG emissions [28–31], they are limited to reflect overall GHG emissions from Macao's energy consumption. First, these studies only take into account only one or a few energy products, which do not reflect the complete scope of Macao's energy consumption. Second, almost all of these studies only focus on direct emissions and do not include indirect emissions. In addition, as a special administrative region, calculation of Macao's GHG emissions is an indispensable part of the whole nation's emission reduction action. However, a comprehensive and detailed analysis of energy consumption and its related GHG emissions in a time series is still lacking. As the economy as well as the population is expected to continue to grow in the near future [31], Macao has to face greater pressure on energy security and GHG abatement. As a consequence, evaluation and investigation of Macao's energy consumption and its related GHG emissions is vital for developing Macao's energy and GHG reduction plans.

Therefore, this paper aims to draw a full picture of energy consumption and estimate related GHG emissions from 2000 to 2010 in Macao, using the latest data. This paper also outlines the underlying factors that have an effect on Macao's energy consumption and GHG emissions. To our knowledge, this is the first review on energy consumption as well as comprehensive accounting for energy-related GHG emissions for Macao. The results presented in this study could be used as a reference to understand energy consumption and its related GHG emissions for cities. The rest of this paper is organized as follows: Section 2 describes the methodology and data sources used in this paper;

Table 1
GHG emission factors of different fuel types.

Fuel energy	Direct emission factors				Indirect emission factors[c]
	CO_2[a] Unit: kg/Tj	CH_4[a]	N_2O[a]	GWP[b] Unit: t CO_2 e./Tj	GWP Unit: t CO_2 e./Tj
Gasoline	69,300	3	0.6	69.5	10.7
Kerosene	71,900	3	0.6	72.1	12.7
Gas oil and diesel	74,100	3	0.6	74.3	10.7
Fuel oil	77,400	3	0.6	77.6	10.1
Liquefied petroleum gas	631,00	1	0.1	63.2	11.0
Traditional fuels	112,000	1	1.5	112.3	77.9
Natural gas	56,100	1	0.1	56.2	20.9

[a] *Source*: IPCC [32].
[b] *Source*: GHG emission factors are calculated by using GWP in this paper, based on the emission factors given by IPCC [32].
[c] *Source*: Derived from Lai [40].

an overview of Macao's energy consumption is presented in Section 3; detailed results of GHG emissions from Macao are shown in Section 4; in Section 5 we discuss how information obtained in this study applies to Macao's future energy and GHG emission reduction plans; finally, conclusions are drawn in Section 6.

2. Methodology and data sources

Data on Macao's energy usage were compiled from the Macao Statistics and Census Service and the annual reports of Macao Electricity Company. All the three major GHG emissions as CO_2, CH_4 and N_2O are calculated and presented in CO_2 equivalent (CO_2 e.) based on Global Warming Potential (GWP), as 1:21:310 for CO_2:CH_4:N_2O according to [32]. Moreover, embodied GHG emissions from Macao's energy consumption are evaluated in this study, based on ecological multi-scale input–output analysis of environmental emissions and resource use [33–39]. In so doing, beyond the direct GHG emissions released by energy combustion within the territory of Macao, indirect GHG emissions produced by the extraction, processing and transportation of energy outside Macao for use in Macao are also included.

2.1. Fuel energy consumption

GHG emissions (t CO_2 e.) attributable to fuels are determined by:

$$GHG_{fuel} = \sum_i C_{fuel,i} \times EF_{fuel,i} \tag{1}$$

where $C_{fuel,i}$ is given for fuel type i in *Balance of Energy*. $EF_{fuel,i}$ represents embodied emission factors (direct plus indirect) for each fuel type i . The direct emission factors for fuels are collected from IPCC [32]. Indirect emission factors are provided by previous studies which have constructed energy and GHG emissions data suitable at different scales [33,34,40]. Following these studies, the GHG emission factors for Macao's energy consumption were derived by using some existing GHG emission data sources (Table 1).

2.2. Electricity consumption

Macao's electricity comes from three sources: electricity generated by local power plants, electricity generated by municipal solid waste (MSW) incineration and electricity imported from mainland China. We calculated the GHG emissions for each of the three different sources. The GHG emission of electricity is determined by both technology and fuel mix [31]. Since the fuel mix and technology level have changed over the years [28,41–50], emission factors of electricity vary more or less over time. As a result, it is necessary to update the GHG emissions factor of electricity. Some researchers have recently proposed methodologies for quantifying electricity emissions or even computed electricity emission factors at different scales by applying various approaches [16,40]. Following these studies, we can calculate embodied (direct and indirect) GHG emission factors of electricity from different sources as follows. To calculate GHG emissions caused by total energy consumption, we subtracted the GHG emissions from fuel consumption in order to avoid double accounting.

(1) The emission factor of Macao's imported electricity can be updated by using

$$EF_{im,n} = EF_{fuel,i} \times \frac{I_n}{I_{2007}} \tag{2}$$

where $EF_{im,n}$ is the GHG emission factor for electricity imported from mainland China in the year n. $EF_{im,2007}$ is the GHG emission factor in 2007, which is calculated based on Chinese input–output table in 2007 [33]. I_n/I_{2007} is the ratio of GHG intensity in the year n compared to that of 2007. I_n is derived from previous research [16,51–54].

(2) Since the fuel mix and local electricity generation efficiency also have changed in Macao (see Fig. 1 and Table 2), we update the data by using the following formula:

$$EF_{local,n} = \frac{1}{\eta_n} \sum_i \lambda_{i,n} \times EF_i \tag{3}$$

where $EF_{local,n}$ represents the GHG emission factor for Macao's local electricity generation in the year n. n_n stands for efficiency in the year n. $\lambda_{I,n}$ is the ratio of fuel energy i input to electricity generation in the year n. EF_i is the emission factor of fuel energy i, which are taken from [40] based on systems input–output analysis. The GHG emission factors of both local electricity and imported electricity in different years are presented in Table 3.

(3) Emission factor of MSW incineration is 0.7880 kg/(kW h), which is obtained from He et al. [66].

(4) GHG emissions from electricity consumption can be calculated as follows:

$$GHG_{electricity} = \sum_i C_{electricity,i} \times EF_{electrcity,i} \tag{4}$$

where $GHG_{electricity}$ is the GHG emission from electricity consumption; $C_{electricity}$ is electricity from each source i (i.e., imported electricity, local electricity and electricity from incineration); $EF_{electricity}$ is the emission factor of electricity from source i.

2.3. GHG emissions from sectoral energy consumption

Energy consumed by sectors as end-users includes both fuel and electricity. The GHG emissions released from sectors' energy consumption can be calculated by the following equation:

$$GHG_i = \sum_j C_{i,j} \times EF_j \tag{5}$$

where GHG_i is the GHG emissions caused by sector i's energy consumption; j is energy type; $C_{i,j}$ is energy of type j consumed by sector i ; EF_j is the emission factor of energy type j.

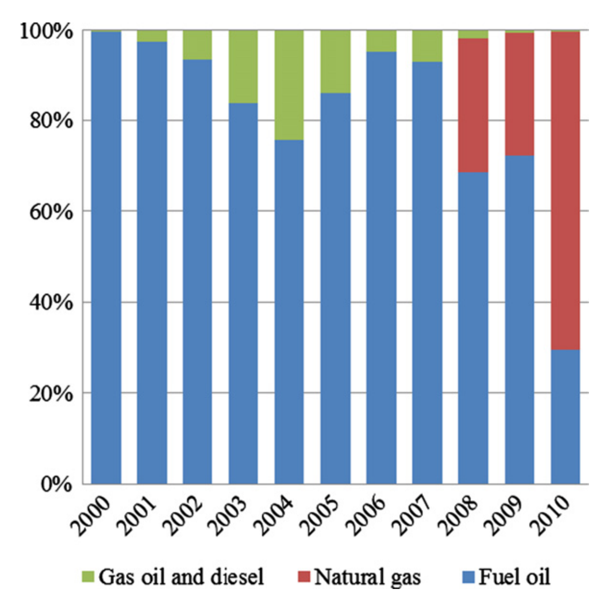

Fig. 1. Fuel mix for local electricity generation in Macao.

Table 2
Energy efficiency for local electricity generation.
Source: Authors' calculation based on *Balance of energy* [55–65].

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Efficiency (%)	43.46	43.00	41.99	42.94	41.53%	44.61	46.15	47.00	47.72	47.00	40.31

Table 3
GHG emission factors for electricity generation from 2000 to 2010 (Unit: t CO_2 e./Tj).

Year	$EF_{im,n}$ [a]	$EF_{local,n}$ [b]
2000	2.36E+02	1.73E+02
2001	2.31E+02	1.75E+02
2002	2.29E+02	1.79E+02
2003	2.23E+02	1.74E+02
2004	2.26E+02	1.80E+02
2005	2.27E+02	1.69E+02
2006	2.23E+02	1.62E+02
2007	2.17E+02	1.58E+02
2008	2.28E+02	1.47E+02
2009	2.13E+02	1.50E+02
2010	2.08E+02	1.51E+02

[a] Calculated by authors based on Eq. (2).
[b] Calculated by authors based on Eq. (3).

Table 4
Energy consumed by fuel types (Unit: Tj).
Note: "–" means not available Source: [55–65].

Year	Gasoline	Kerosene	Gas oil and diesel	Fuel oil	LPG	Traditional fuels	Natural gas
2000	1337	454	3540	12,446	1115	31	0
2001	1340	460	3872	12,512	1117	34	0
2002	1381	463	4643	12,970	1194	40	0
2003	1460	376	5768	12,173	1274	58	0
2004	1567	365	7992	12,452	1329	54	0
2005	1733	339	7186	14,117	1402	47	0
2006	1767	303	6199	12,430	1480	49	0
2007	1984	289	6644	10,843	1615	52	0
2008	2070	255	5866	6,363	1836	–	3218
2009	2243	230	5479	7,924	1806	–	3643
2010	2421	211	5466	2,814	1851	–	6029

3. Review of Macao's energy consumption 2000–2010

Table 4 lists fuels consumed in Macao at the period of 2000–2010. The territory under Macao's jurisdiction is so small that there are no indigenous sources of energy; consequently, Macao is a one hundred percent net energy importer. Macao's internal social and economic activities necessarily require external energy supply. Mainland China, Singapore, UK and Saudi Arabia are Macau's top four suppliers of fuel energy [55–65]. Taking the year 2008 as an example, analysis of the quantity of fuel imports indicates that nearly 86.0% of fuels were imported from Singapore and mainland China [63]. According to *Balance of Energy* [55–65], Macao imports gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas (LPG), traditional energy (such as firewood, coal), natural gas and electricity. *Balance of Energy* [55–65] also provides data on energy consumed by individual sectors, comprising "industry", "construction", "transportation", "commerce, hotels and restaurants", "household", "services" and "other sectors."

3.1. Fuel energy consumption

Fuel oil, used mainly for local electricity generation, was the most-used fuel from 2000 to 2009. However, after its use peaked at 14,117 Tj in 2005, its consumption saw annual reduction and sharply declined to 2814 Tj in 2010, because other energy sources were introduced as an alternative for local electricity generation. Gas oil and diesel had a broad usage; a large proportion of its consumption is attributed to local electricity generation and transportation, while only a small fraction is used for hotels, construction, etc. Similar to fuel oil, gas oil and diesel consumption also had an inverted-U trend as it first rose from 3540 Tj in 2000 to 7992 Tj in 2004, then dropped to 5466 Tj in 2010. The fluctuation of gas oil and diesel consumption can also be explained by the introduction of alternative energy sources. Gasoline is primarily used for land transportation. Along with the rising number of vehicles, gasoline consumption grew from 1137 Tj in 2000 to 2421 Tj in 2010. LPG is mainly consumed by households and by commerce, restaurants and hotels, with a total quantity of less than 2000 Tj in the accounted period. Kerosene is mainly used for air transportation and for commerce, restaurants and hotels. However, due to data confidentiality, data on kerosene consumed by air transportation is not available. As a result, this study does not consider the consumption of aviation kerosene, which would lead to uncertainty in the results. To further optimize the structure of energy supply, Macao launched clean energy program to make efforts to diversify its sources of energy imports [48]. In this context, natural gas has been chosen as an alternative by Macao's government to replace fuel oil and diesel used by local electricity generation because of natural gas' relatively low emissions of air pollutants. In 2007, Macao Natural Gas Corporation and China Power Investment Corporation began to co-construct Zhuhai Huangmao Island liquefied natural gas, receiving final and ancillary facilities for Macao and the neighboring regions' gas supply. This initiative laid the foundation for the introduction of natural gas and for the transition to the use of clean energy. At the beginning of 2008, Macao's natural gas power plant was put into use and supplied 25.38% of Macao's fuel for local electricity in 2008; this proportion rose significantly to 70.33% in 2010 [37,63–65]. In recent years, Macao's agriculture gradually disappeared under the rapid ongoing urbanization. As a result, only an extremely small quantity of traditional energy such as firewood is used by households.

3.2. Electricity consumption

Electricity accounts for more than 50% of Macao's total energy consumption. Households; commerce, restaurants and hotels; the service industry; industry; and construction together contribute to approximate three quarters of Macao's total electricity consumption [55–65]. The most important local electricity supply sources are the Macau Power plant and the Coloane Power plant owned by Macau Electricity Co., Ltd. using fuels and local incinerators to generate electricity. With an annual growth rate of 8.70%, total electricity consumption increased from 1728 GW h to 3979 GW h between 2000 and 2010 (Fig. 2).Within these broader statistics, local electricity generated from fuel combustion varied significantly between 1077 GW h (2010) and 2027 GW h (2005). The amount of electricity generated from MSW incineration was very small, with an amount of less than 125 GW h in the accounting period, making up only about 3% of the total electricity consumption.

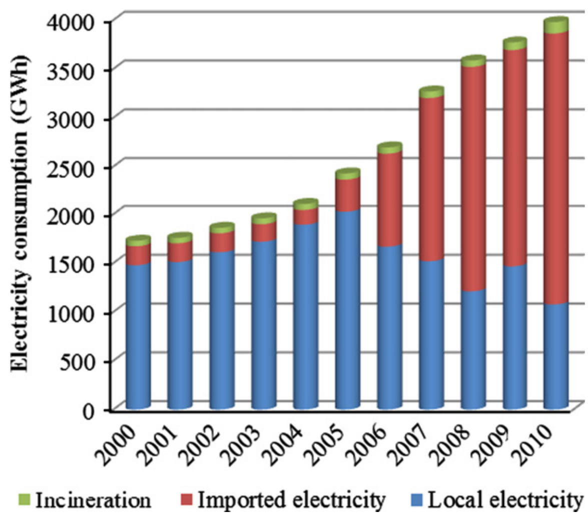

Fig. 2. Total electricity consumption in Macao 2000–2010.

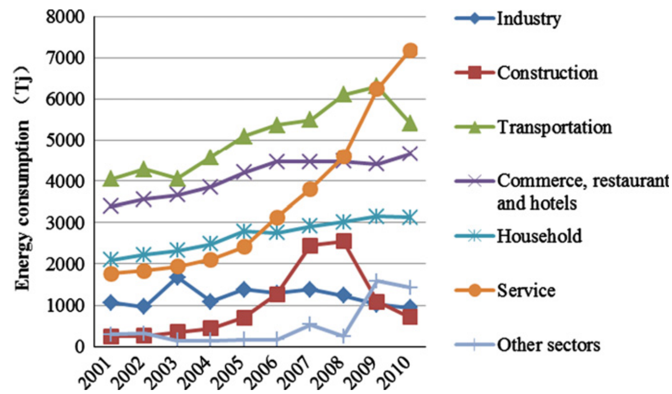

Fig. 3. Energy consumed by sectors.

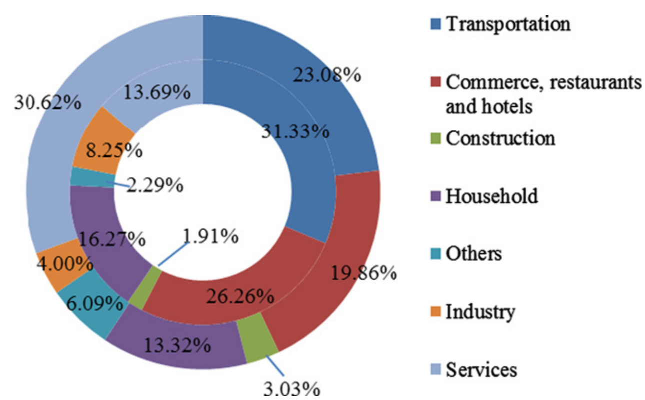

Fig. 4. Comparison of energy structure in 2001 and 2010.

Concerns about energy security and environmental protection has led to the ever-greater share of imported electricity from mainland China to meet Macao's increasing electricity requirement and ensure a stable supply of electricity. Since 1980s Macao has purchased electricity from Guangdong Power Grid in ever-increasing quantities to satisfy growing energy demand for social and economic development. However, imported electricity did not dominate Macao's electricity consumption until 2006. In the first 5 years of the accounting period, imported electricity accounted for less than 15% of the total electricity consumption. With the increasing sophistication of transmission facilities, the imported electricity soared from 341 GW h in 2005 and fast grew to 2786 GW h in 2010, representing 70.33% of Macao's total electricity consumption [55–65].

3.3. Sectoral energy consumption

According to statistics provided by Macao Census Bureau, energy consumed by all sectors shows varying degrees of growth in different years, compared to that of 2001. As the statistics provided by Macao Census Bureau did not give specific information on sectoral energy consumption in 2000, our analysis on sectoral energy consumption had to start from 2001.

Sectoral energy consumption is closely linked to Macao's economy. From Fig. 3 we can see energy consumed by the service industry grew dramatically since the liberalization of Macao's gaming industry. In 2010, the service industry consumed 7185 Tj of energy, which is about 4.4 times that of 2001. As an important energy consumer, the commerce, restaurant and hotel sector, which depends on visitor arrivals, average occupancy rate, and per-capita spending of visitors, also saw energy consumption growth, overwhelmingly influenced by mainland Chinese, especially since the implementation of mainland China's "Individual Visit Scheme" in 2003.

Energy consumed by transportation fluctuated between 2001 and 2010; it increased from 4045 Tj in 2001 to 6308 Tj in 2009, and then dropped to 5416 Tj in 2010. However, due to confidentiality, energy consumed by air transport is not included in this study [25,67–76], which results in a low estimate.

Energy used by households increased from 2100 Tj in 2001 to 3125 Tj in 2010, due to the growing population. The energy used by construction displays an inverted-U shaped trend because of the change of investments in Macao's infrastructure [72–76]. In general, industry contributed less and less to Macao's economy during the study period. Energy consumed by industry decreased from its high of 1682 Tj in 2003 to 939 Tj in 2010. Energy consumed by other sectors changed from year to year, and only accounted for small proportion of total consumption.

The structure of sectoral energy consumption also changed during the accounting period, as depicted in Fig. 4. In 2001, transportation was the biggest energy end-user, contributing to 31.33% of the total end-use consumption, followed by the commerce, restaurants and hotels sector and households. While in 2010, services replaced transportation as the number one energy consumption sector, responsible for 30.62% of the total. Transportation became the second biggest end-user in 2010, still consuming 23.08% of the total. The commerce, restaurants and hotels sector and households ranked 3rd and 4th, respectively, in the amount of energy consumed.

3.4. Total energy consumption and per capita energy consumption

Generally, Macao's energy consumption has increased since Macao's sovereignty was returned to China. However, it has also gone through ups and downs from 2000 to 2010, as shown in Fig. 5. Due to factors such as rapid urbanization, population growth and economy boom in recent years, especially the liberalization of the gaming industry after 2002, Macao's energy consumption reached a high value of 33,347 Tj in 2005, increasing by 33.69% over the year of 2000. With the adjustment of energy structure started in 2006 and changing price of different prices, the total energy used by Macao slightly went down from 2006 to 2010. From the per capita point of view, the trend of per capita energy consumption is similar to that of total energy consumption increased from 56.96 Gigajoules (Gj) per person in 2000 to

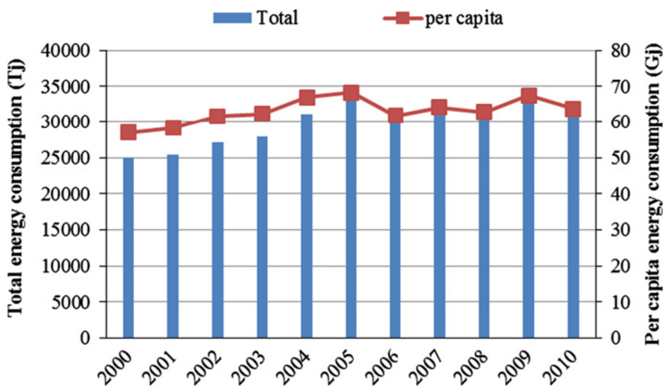

Fig. 5. Total energy consumption and per capita energy consumption in Macao.

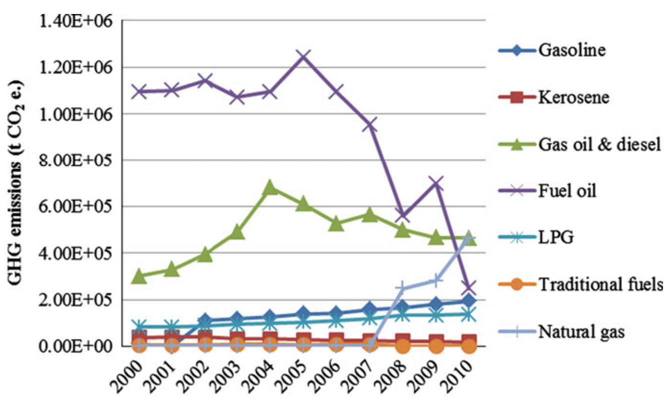

Fig. 6. GHG emissions from fuel consumption.

68.32 Gj per person in 2005, and finally dropped to 63.69 Gj in 2010.

4. Results

4.1. The GHG emissions of fuel energy consumption

After identifying the GHG emission factor of each fuel used in Macao, GHG emissions for fuels were obtained as shown in Fig. 6 The GHG emissions from fuel consumption in Macao demonstrated an apparent fluctuation during 2000–2010. The total amount fuel energy GHG emissions first increased from 1.63E+06 t CO_2 e. in 2000 to 2.13E+06 t CO_2 e. in 2005, then began to decline and decreased to 1.53E+06 t CO_2 e. in 2010. Of all fuel types, the consumption of fuel oil released the greatest amount of GHG emissions from 2000 to 2009, which were 1.10E+06 t CO_2 e. in 2000 and 6.97E+05 t CO_2 e. in 2009, accounting for 67.48% and 39.16% of the total fuel emissions, respectively. However, the change in GHG emissions from fuel oil is also the greatest in this period. Between 2006 and 2010, it dropped sharply from its high of 1.24E+06 t CO_2 e. to 2.48E+05 t CO_2 e., with a reduction rate of 80.00%. This decrease resulted from two factors: one is the increasing share of imported electricity; the other is the introduction of natural gas as an alternative for local electricity generation. We can see that a rebound in fuel oil emissions appeared in 2009, when Macao used fuel oil to compensate for reduced imported electricity, due to the high price of imported electricity [64]. The second highest GHG emissions were from gas oil and diesel, which is also used by local power plants. Along with the amount of gas oil and diesel consumed by Macao, the GHG emission first grew from 3.01E+05 t CO_2 e. in 2000 to 6.11E+05 t CO_2 e. in 2005, then declined annually to 4.65E+05 in 2010. The GHG emissions from introduced natural gas for local electricity generation had a rapid growth trend; it increased from 2.48E+05 t CO_2 e. in 2008 to 4.64E+05 t CO_2 e. in 2010, with an increase by 87.10% in just two years. Both Gasoline and LPG saw slight growth in this period, while kerosene and traditional fuel witnessed a slow decline. GHG emissions from the four remaining fuels make up only a small part of total fuel emissions, accounting for 12.91–22.86% between 2000 and 2010.

4.2. The GHG emissions of electricity consumption

As a second energy carrier, electricity requires conversion processes; emissions from those processes are copious and often occur at locations far away from where the electricity is consumed. This has indirectly induced high emissions beyond the territory of Macao. The results indicate that a large amount of GHG emissions was generated by electricity consumption in Macao from 2000 to 2010 (Fig. 7). The total GHG emissions released by electricity consumption grew from 1.25E+06 t CO_2 e. in 2000 to 2.86E+06 t CO_2 e. in 2010, with an annual growth rate of 8.63%. However, a slight decrease appeared in 2009, compared to 2008. In terms of emission structure of electricity, the proportion of GHG emissions caused by electricity from different sources varied significantly over time, along with the changing structure of electricity consumption. From 2000 to 2006, GHG emissions from local electricity generated by fuels were the biggest contributor to electricity emissions. Especially in the first 6 years, GHG emissions from local electricity were responsible for more than 80% of electricity consumption emissions, while since 2005, GHG emissions induced by imported electricity began to grow at very fast pace, surpassing that of local electricity in 2007. Emissions from imported electricity accounted for 72.89% of electricity emissions in 2010, with an amount of 2.09E+06 t CO_2 e. GHG emissions from electricity generated by MSW incineration steadily increased from 5.19E+04 t CO_2 e. in 2000 to 8.71E+04 t CO_2 e. in 2010, but only accounted for a small fraction (less than 4.50%) of emissions from electricity consumption.

Because electricity is the basic requirement for the service industry to offer lighting and air-conditioning and to operate infrastructure such as hotels and casinos, GHG emissions related to electricity consumption accounted for over two thirds of the total GHG emissions. The share of emissions from fuel consumption declined with the increase in imported electricity.

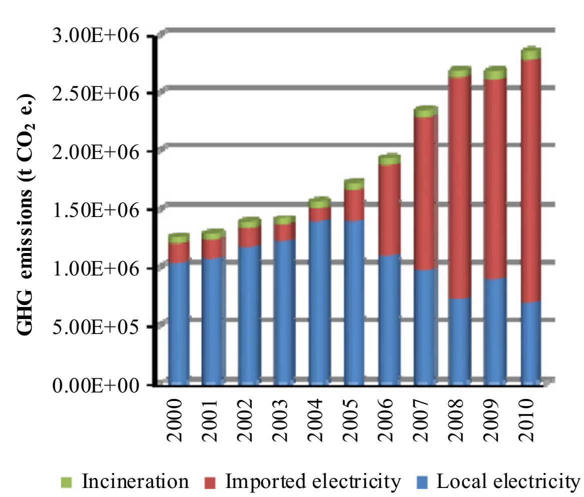

Fig. 7. GHG emission for electricity consumption.

4.3. GHG emissions from sectoral energy consumption

The sectoral analysis shows that GHG emissions for service industry energy consumption increased significantly, and this sector became the biggest emitter after 2006 (Fig. 8), due to the booming gaming industry and its related tourism. The service industry emitted 1.40E+06 t CO_2 e. of GHG in 2010, approximately 4 fold of that of 2001 and accounting for 42.34% of total emissions. As an important energy consumer, the commerce, restaurants and hotels sector is also a big contributor to sectoral energy consumption. The GHG emissions reached 6.52E+05 t CO_2 e. in 2010, which was 40.52% higher than that of 2001. However, due to the declining number of visitors in 2008 and 2009 caused by the global economic crisis, GHG emissions for the commerce, restaurants and hotels sector decreased in those two years. Along with the rising population and living standards, GHG emissions from household energy consumption steadily grew from 3.23E+05 t CO_2 e. in 2001 to 5.43E+05E+05 t CO_2 e. in 2010, with a growth rate of 64.55%. As for transportation, steadily increasing vehicle numbers, passenger and container flow by land, and seaborne container throughput during 2001–2009 led to growing transportation energy consumption and its related GHG emissions, while in 2010, both passengers and commodities transported in or out of Macao decreased, which caused the decline in GHG emissions from transportation.

It can be seen from Fig. 8 that GHG emissions from energy consumption by construction varied significantly during the period from 2004 to 2010. Motivated by the liberalization of gaming industry in 2002, many investors rushed to Macao to invest money in the construction of buildings such as casinos, hotels, which led to rapid growth of energy consumption as well as GHG emissions from construction. In 2008, GHG emissions from construction reached 4.47E+05 t CO_2 e., which is about 17 times that of 2001. Strongly influenced by the world economic crisis, investment in construction declined so quickly that energy consumed by this sector also greatly decreased. As a result, the energy consumption related GHG emissions dropped to 8.18E+04 t CO_2 e. in 2010.

Unlike some mega-cities in China [3], industry is not the pillar of Macao's economy, and most of the factories in Macao are textile factories whose energy intensity is much less than that of heavy industries such as steel production. For this reason, the GHG emissions for Macao's industry energy consumption are relatively small, accounting for 3.99–10.25% of the total GHG emissions from 2001 to 2010. As compared to other sectors, industry consumed only a very small amount of energy and released a fraction of GHG emissions, which kept a relative stable trend from 2001 to 2010.

Within the accounting period, the structure of sectoral GHG emissions for energy consumption also varied significantly (Fig. 9). It must be noted that the structure of sectoral energy consumption does not equal that of sectoral GHG emissions because the proportion of each energy type consumed differs from sector to sector.

4.4. Total and per capita emissions

As presented in Fig. 10, total GHG emissions from Macao's energy consumption doubled during the study period, increasing from 1.85E+06 t CO_2 e. in 2000 to 3.70E+06 t CO_2 e. in 2010. It can also be seen that the trend in per capita GHG emissions is similar to that of total GHG emissions. The per capita GHG emissions for Macao's energy consumption increased from 4.22 t CO_2 e. in 2000 to 7.20 t CO_2 e. in 2010, with a growth rate of 70.62%. However, due to the global economic crisis, GHG emissions saw a decline in 2009, compared to 2008.

The results show that direct GHG emissions for Macao's energy consumption have witnessed fluctuations (Fig. 10) from 2000 to 2010. From 2000 to 2005, the direct GHG emissions increased from 1.48E+06 t CO_2 e. to 1.92E+06 t CO_2 e. because of the growing energy requirements of Macao. Emissions then decreased to 1.35E+06 t CO_2 e. in 2010. In contrast to direct emissions, indirect GHG emissions remained stable in the first five years. Since 2005, Macao adjusted its energy structure and began to increase the share of imported electricity; as a consequence, indirect GHG emissions, mainly embodied in imported electricity, grew steadily and quickly exceeded direct emissions in 2008 and finally reached a record high of 2.35E+06 t CO_2 e. in 2010. As for the proportion of direct versus indirect GHG emissions, the percentage of direct GHG emissions significantly decreased from 80.14% in 2000 to 36.52% in 2010. This means that indirect GHG

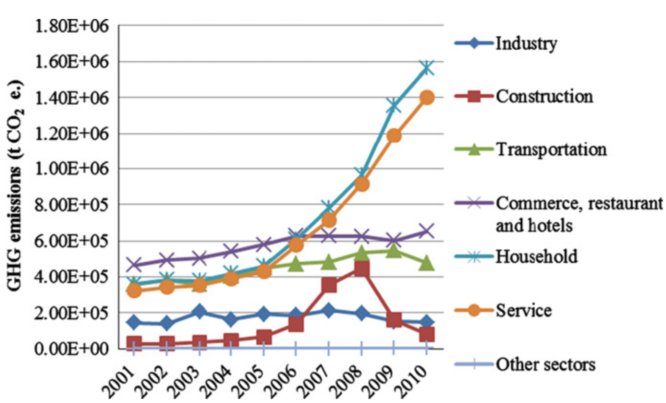

Fig. 8. GHG emissions from sectoral energy consumption.

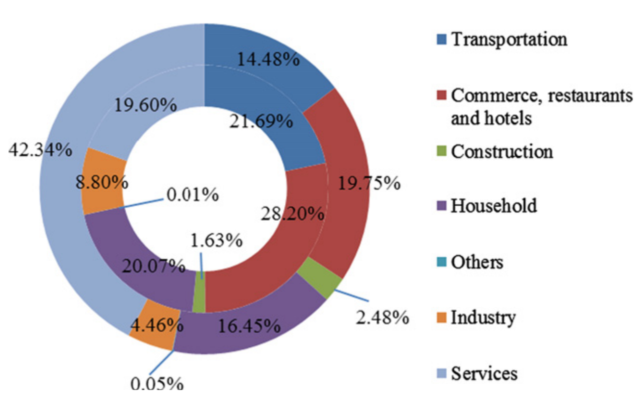

Fig. 9. Comparison of GHG emissions structure in 2001 and 2010.

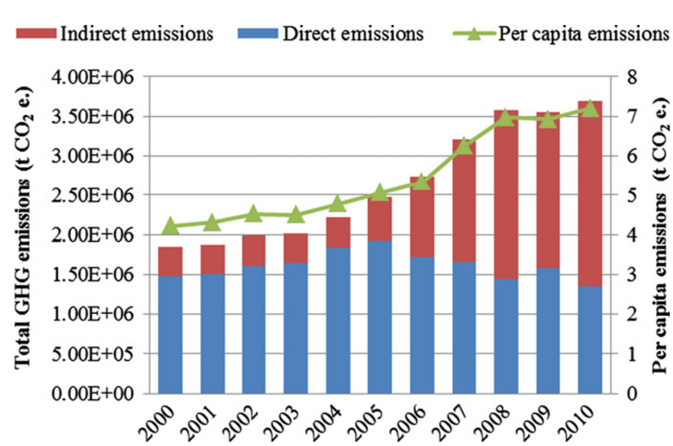

Fig. 10. Total GHG emissions for Macao's energy consumption 2000–2010.

emissions replaced direct emissions as the dominant contributor to the embodied GHG emissions.

5. Discussion

This study draws a picture of Macao's energy consumption, as well as its related GHG emissions, for the period of 2000–2010. The results we obtained in this study provide some important insights for Macao's future plans regarding energy consumption and its related GHG emissions.

As far as energy consumption related GHG emissions are concerned, the current understanding of direct emissions caused by fossil fuel combustion is not sufficient to draw a full picture of GHG emissions caused by energy consumption in Macao. From Fig. 10 we can see that since 2005, direct GHG emissions steadily declined while the overall embodied GHG emissions show an opposite trend. This implies that the so-called reduction of direct GHG emissions is simply a transfer of emissions to other regions as exporters. For instance, from a direct accounting point of view, imported electricity consumption can be called "emission-free" because there is no direct emission from the use of imported electricity. Yet in fact, imported electricity is characterized by very high GHG emissions in mainland China because it mainly originates from coal combustion, which has a very high GHG emission factor. What is more, the exploitation, transportation of energy outside of Macao, which also emits GHGs, is ignored under the framework of direct accounting. Ignoring indirect emission results in the GHG leakage problem, against which we have to resort to the consumption-based method [77]. From the consumption based point of view, the GHG emissions attributed to Macao are much larger than the actual physical emissions that are released from fuel burned within the city's territory. As a consequence, with regard to Macao's consumer responsibility, the design of mitigation policy must be extended beyond the territory and take indirect emissions into account. Otherwise, those living outside of Macao have to pay a price for Macao's energy consumption.

Although the overall energy consumption and its related GHG emissions witnessed significant growth during the accounting period, both the energy intensity (per GDP energy consumption) and per capita GHG emissions were still much lower than most countries and cities across the world, as presented in Table 5 and Fig. 11. Generally, energy intensity corresponds to the level of economic development, to some extent [78]. Similar to the developed countries/regions with better economic performance (expressed in GDP per capita), Macao is characterized by low energy consumption per unit GDP. This can be explained by Macao's special economic structure, which is dominated by low-emission service industries such as gaming and tourism rather than emission-intensive industries such as steel production.

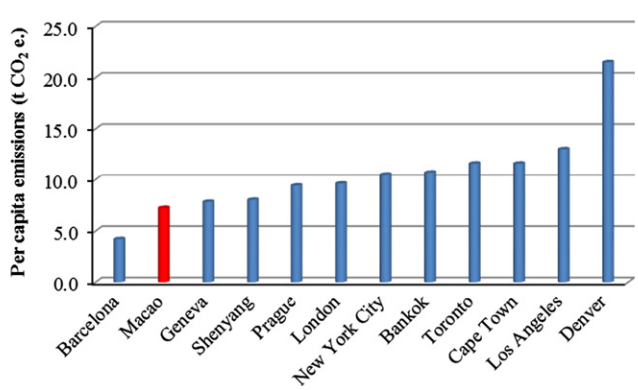

Fig. 11. Per capita GHG emissions for energy consumption in selected large cities.

Table 5
Energy intensity of Macao and other countries/regions.
Source: Derived from office for the development of the energy sector. See also in http://www.gdse.gov.mo/eng/GDSE_Pages/GDSEindex.asp.

Country and region	Per capita (Gj/1E+04 USD)
Macau	13.60
Germany	34.27
France	35.87
Japan	45.32
The U.S.A	64.03
Singapore	74.08
The Philippines	85.29
Korea	106.15
Thailand	138.10
India	145.45
Malaysia	153.68
China	182.52

The high economic growth associated with the booming service industry and increasing population are the major contributors to energy consumption and GHG emissions during the period of 2000–2010. As industry gradually falls into decline, Macao keeps moving toward a service-oriented economic structure. According to China's 12th Five-Year Plan, Macao is intended to become the world tourism and leisure center [79]. As a result, Macao's economy will be more dependent on the service industry. To construct, operate and maintain a growing number of casinos, hotels, shopping malls and exhibition centers, as well as meet the rising living standard of residents, requires more energy, indicating the potential for increasing emissions in the future. In addition to creating greater GHG mitigation pressure, this would pose a greater challenge to Macao's energy security, as it is a complete net importer of energy.

Macao has recently taken some measures to confront these issues. For example, Macao has introduced natural gas, a cleaner and friendlier energy with a smaller GHG emission factor, to gradually take the place of fuel oil and gas oil and diesel, which not only have comparatively higher emission factors but are also more polluting. Macao is also planning to utilize solar and wind energy in the future to increase local capacity and reduce its dependence on energy from abroad [48,49]. At the same time, the Government has begun to pay attention to the role of public education, conducting surveys to advertise the importance of GHG mitigation and hosting energy saving contests to promote optimal power saving measures and to cultivate a habit of energy conservation.

However, much more needs to be done, as these current measures are far from enough to cope with the current serious situation. As a special administrative region of China, Macao can take advantage of its high degree of autonomy to form policies in light of local reality. Given this opportunity, responsibility ultimately falls on the Government to make a long-term plan, involving all sectors and residents, to guide its future energy policies. To ensure such policies are fulfilled, Government will ideally structure multiple regulations and incentives. For instance, Macao should give priority to continuing to diversify its energy sources and reduce its dependence on imported energy. As the climate in Macao is typical subtropical, renewable energies such as solar energy and wind energy have appreciable potential to be explored [48–50]. At the same time, it is urgent for Macao to improve energy efficiency and minimize energy consumption.

Macao can also combine strong leadership from government with appropriate financial and tax policies to encourage environmental responsibility [80], such as rewarding low-carbon buildings with more subsidies and introducing a carbon tax. Education programs to increase residents' awareness of energy management and GHG mitigation is also important for Macao.

6. Concluding remarks

This paper has presented a full picture of energy consumption in Macao; quantified GHG emissions embodied in various energy types, investigated GHG emissions caused by sectoral energy consumption and analyzed the importance of indirect GHG emissions. We have also tried to link the characteristics of GHG emissions caused by energy consumption with economic change in the first decade since the handover of sovereignty to China.

Both energy consumption and its related GHG emissions for Macao saw significant growth from 2000 to 2010. Energy used in Macao rapidly increased from 24,944 Tj in 2000 to 32,700 Tj in 2010, with a growth rate of 31.10%. Embodied GHG emissions from energy consumption were 1.85E+06 t CO_2 e. in 2000, and this number doubled by 2010. The indirect emissions produced by Macao's energy consumption surpassed the direct emissions in 2008, mainly due to increased importing of electricity from mainland China, with its associated emissions outside Macao. In 2010, service, transportation and the commerce, restaurant and hotels sector were the three biggest energy consumers as well as GHG emitters. Moreover, energy intensity and per capita GHG emissions, which also increased in the same period, were still lower than most of the countries/cities, due to Macao's service-oriented economy.

Compared to the existing studies on the energy related GHG emissions at city level, ours has two major differences. First, most published literature addressing GHG emissions from cities' energy consumption have followed the framework of IPCC which cannot track the indirect emissions embodied in associated process or services because it only concentrates on emissions caused by primary fuel energy combustion. However, city's energy consumption does not only directly emit GHGs by fuel combustion, but also induces indirect emissions from processes such as fuel production, refining and transportation. As a consequence, these previous studies which adopt direct emission factors are not able to cover indirect emissions and thus GHG leakage appears. In contrast, the emission factors applied by our study are derived from existing databases which is based on input–output analysis, which is an applicable framework to calculate cumulative GHG emissions related to energy consumed by economies at different scales [33,34]. Therefore, the emission leakage problem is avoided in our study. Second, a large amount of researchers just focus on relationship between energy consumption and GHG emissions in one specific year without considering the social and economic changes at different stages of city's development, while our study on Macao has conducted a detailed inventory of energy related GHG emissions in light of economic and policy development in a time series. With the help of findings in our study, local government can get some clues to implement appropriate energy conservation and GHG emission mitigation measures against the economic and policy changes.

Since the Kyoto Protocol was extended to Macao, the Government has realized the urgency and importance of energy saving and GHG mitigation. Actions such as introducing clean energy, increasing the share of imported electricity, publicizing the importance of energy saving, and subsidizing initiatives for energy development have been taken [50]. However, some of these actions have focused only on energy production from direct fuel combustion. The lack of a consumption-based perspective makes the so-called emission reduction a leakage problem. What is worse, it is expected that more and more energy will be used to sustain Macao's social and economic activities, as Macao's development continues at a rapid pace [81]. As a result, the current understanding of Macao's energy saving and GHG mitigation is not sufficient for appropriate decision-making. Future measures should be based on local reality under the framework of systems analysis rather than direct accounting.

The unveiled China's 12th Five-Year Plan decides to build Macao as the world tourism and conference center [79], which calls for low-carbon policy to help to achieve this goal. As a result, energy conservation and GHG mitigation are issues that determine the sustainability and future development of Macao. In order to tackle these issues, various efforts need to be made, including diversifying energy sources; improving energy efficiency; introducing financial and tax policies; and implementing education program. Results obtained in our study are hoped to offer useful information to help the local government to direct energy and GHG emission reduction issues.

Acknowledgement

This study has been supported by National Natural Science Foundation of China (Grant No. 11272012) and Innovation Project Foundation of Beijing Academy of Science and Technology (Grant No. PXM2011_178215_000003). The authors also thank Heather Ramsay and Ling Shao for providing comments to draft manuscript.

References

[1] UN. World Urbanization prospects, the 2007 revision. New York, population division of the department of economic and social affairs United nations; 2008.
[2] IEA. World energy outlook. Paris, International Energy Agency; 2008.
[3] Dhakal S. Urban energy use and carbon emissions from cities in China and policy implications. Energy Policy 2009;37:4208–19.
[4] Bi J, Zhang R, Wang H, Liu M, Wu Y. The benchmarks of carbon emissions and policy implications for China's cities case of Nanjing. Energy Policy 2011;39:4785–94.
[5] Dhakal S. Urban energy use and greenhouse gas emissions in Asian Mega-cities. Kitakyushu, Institute for Global Environmental Strategies 2004.
[6] Li L, Chen C, Xie S, Huang C, Cheng Z, Wang H, Wang Y, Huang H, Lu J, Dhakal S. Energy demand and carbon emissions under different development scenarios for Shanghai, China. Energy Policy 2010;38:4797–807.
[7] IPCC. IPCC fourth assessment report (AR4). Cambridge, Cambridge University Press; 2007.
[8] Milner J, Davies M, Wilkinson P. Urban energy, carbon management (low carbon cities) and co-benefits for human health. Current Opinion in Environmental Sustainability 2012;4:398–404.
[9] Cai B, Liu C, Chen C. City's greenhouse gases (GHGs) emission inventory research. Beijing: Chinese Chemical Industry Press; 2009.
[10] Satterthwaite D. Cities' contribution to global warming, notes on the allocation of greenhouse gas emissions. Environment and Urbanization 2008;20:539–49.
[11] The-climate-group. China's low carbon leadership in cities. London, HSBC climate partnership; 2009. (In Chinese).
[12] Bulkeley H. Cities and the governing of climate change. Annual Review of Environment and Resources 2010;35:229–53.
[13] Parshall L, Gurney K, Hammer SA, Mendoza D, Zhou Y, Geethakumar S. Modeling energy consumption and CO_2 emissions at the urban scale, methodological challenges and insights from the United States. Energy Policy 2010;38:4765–82.
[14] Kennedy C, Steinberger J, Gasson B, Hansen Y, Hillman T, Havránek M, Pataki D, Phdungsilp A, Ramaswami A, Mendez GV. Methodology for inventorying greenhouse gas emissions from global cities. Energy Policy 2010;38:4828–37.
[15] Kennedy C, Steinberger J, Gasson B, Hansen Y, Hillman T, Havra´ne M, Patak D, Phdungsil A, Ramaswam A, Mende GV. Greenhouse gas emissions from global cities. Environmental Science & Technology 2009;43:7297–302.
[16] Liu Z, Liang S, Geng Y, Xue B, Xi F, Pan Y, Zhang T, Fujita T. Features, trajectories and driving forces for energy-related GHG emissions from Chinese mega cites, the case of Beijing, Tianjin, Shanghai and Chongqing. Energy 2012;37:245–54.

[17] Ramaswami A, Hillman T, Janson B, Reiner M, Thomas G. A demand-centered, hybrid life-cycle methodology for city-scale greenhouse gas inventories. Environmental Science & Technology 2008;42:6455–61.
[18] Xi F, Geng Y, Chen X, Zhang Y, Wang X, Xue B, Dong H, Liu Z, Ren W, Fujita T, Zhu Q. Contributing to local policy making on GHG emission reduction through inventorying and attribution, a case study of Shenyang. China Energy Policy 2011;39:5999–6010.
[19] Yu W, Pagani R, Huang L. CO_2 emission inventories for Chinese cities in highly urbanized areas compared with European cities. Energy Policy 2012;47: 298–308.
[20] Krey, V, Brian, C O N, Bas, V R, Vaibhav, C, Vassilis, D, Eom, JY, Jiang, LW, Yu, NG, Pachauri, S, Ren, XL. Urban and rural energy use and carbon dioxide emissions in Asia. Energy Economics 2012 ;34: S272-S283.
[21] Liu X, Sweeney J. Modelling the impact of urban form on household energy demand and related CO_2 emissions in the Greater Dublin Region. Energy Policy 2012;46:359–69.
[22] Makido, Y, Dhakal, S, Yamagata, Y. Relationship between urban form and CO_2 emissions: evidence from fifty Japanese cities. Urban Climate 2012;2:55-67.
[23] Zhang C, Lin Y. Panel estimation for urbanization, energy consumption and CO_2 emissions: a regional analysis in China. Energy Policy 2012;49:488–98.
[24] Feng, YY, Chen, SQ, Zhang, LX. System dynamics modeling for urban energy consumption and CO_2 emissions: a case study of Beijing, China. Ecological Modelling 2012., http://dx.doi.org/10.1016/j.ecolmodel.2012.09.008, in press.
[25] DSEC. Yearbook of statistics. Macao, Statistics and Census Service of Macao; 2010.
[26] Wikipedia. Macau, 2012. Also available at http//en.wikipedia.org/wiki/Macau.
[27] Chan, VKY. The impact of the global financial crisis on the Entertainment Tourism Industry, A financial engineering case study of Macao from 2007 to 2010. Systems Engineering Procedia 1 (2011); 323–329.
[28] CEM. CEM annual report. Macao, Companhia de Electricidade de Macau; 2007.
[29] DSPA. Macao environmental report 2008–2009. Macao, Macao Environmental Protection Agency, 2010.
[30] Lai TM, To WM, Lo WC, Choy YS. Modeling of electricity consumption in the Asian gaming and tourism center-Macao SAR, People's Republic of China. Energy 2008;33:679–88.
[31] To WM, Lai TM, Chung WL. Fuel life cycle emissions for electricity consumption in the world's gaming center—Macao SAR China. Energy 2011;36: 5162–8.
[32] IPCC. IPCC guidelines for National Greenhouse Gas Inventories. Tokyo, Prepared by the National Greenhouse Gas Inventories Programme. Institute for Global Environmental Strategies; 2006.
[33] Chen GQ, Chen ZM. Carbon emissions and resources use by Chinese economy 2007, a 135-sector inventory and input–output embodiment. Communications in Nonlinear Science and Numerical Simulation 2010;15:3647–732.
[34] Chen GQ, Chen ZM. Greenhouse gas emissions and natural resources use by the world economy, ecological input–output modeling. Ecological Modelling 2011;222:2362–76.
[35] Chen GQ, Shao L, Chen ZM, Li Z, Zhang B, Chen H, Wu Z. Low-carbon assessment for ecological wastewater treatment by a constructed wetland in Beijing. Ecological Engineering 2011;37:622–8.
[36] Chen ZM, Chen GQ. Embodied carbon dioxide emission at supra-national scale, a coalition analysis for G7, BRIC, and the rest of the world. Energy Policy 2011;39:2899–909.
[37] Chen ZM, Chen GQ. An overview of energy consumption of the globalized world economy. Energy Policy 2011;39:5920–8.
[38] Zhang B, Chen GQ. Methane emissions by Chinese economy, Inventory and embodiment analysis. Energy Policy 2010;38:4304–16.
[39] Zhou, JB. Embodied ecological elements accounting of national economy. PhD thesis. Beijing, Peking University ; 2008. (In Chinese).
[40] Lai, TM. Systems accounting of Macao's greenhouse gas emissions. Master thesis. Beijing, Peking University ; 2011. (In Chinese).
[41] CEM. CEM annual report. Macao, Companhia de Electricidade de Macau; 2000.
[42] CEM. CEM annual report. Macao, Companhia de Electricidade de Macau; 2001.
[43] CEM. CEM annual report. Macao, Companhia de Electricidade de Macau; 2002.
[44] CEM. CEM annual report. Macao, Companhia de Electricidade de Macau; 2003.
[45] CEM. CEM annual report. Macao, Companhia de Electricidade de Macau; 2004.
[46] CEM. CEM annual Report. Macao, Companhia de Electricidade de Macau; 2005.
[47] CEM. CEM annual report. Macao, Companhia de Electricidade de Macau; 2007.
[48] CEM. CEM annual report. Macao, Companhia de Electricidade de Macau; 2008.
[49] CEM. CEM annual report. Macao, Companhia de Electricidade de Macau; 2009.
[50] CEM. CEM annual Report. Macao, Companhia de Electricidade de Macau; 2010.
[51] NDRC. Baseline emission factors for regional power grids in China. Beijing, National Development and Reform Commission; 2007. (In Chinese).
[52] NDRC. Baseline emission factors for regional power gridsin China. Beijing, National Development and Reform Commission; 2008. (In Chinese).
[53] NDRC. Baseline emission factors for regional power grids in China. Beijing, National Development and Reform Commission; 2009. (In Chinese).
[54] NDRC. Baseline emission factors for regional power grids in China. Beijing, National Development and Reform Commission; 2010. (In Chinese).
[55] DSEC. Balance of energy. Macao, Statistics and Census Service of Macao; 2000.
[56] DSEC. Balance of energy. Macao, Statistics and Census Service of Macao; 2001.
[57] DSEC. Balance of energy. Macao, Statistics and Census Service of Macao; 2002.
[58] DSEC. Balance of energy. Macao, Statistics and Census Service of Macao; 2003.
[59] DSEC. Balance of energy. Macao, Statistics and Census Service of Macao; 2004.
[60] DSEC. Balance of energy. Macao, Statistics and Census Service of Macao; 2005.
[61] DSEC. Balance of energy. Macao, Statistics and Census Service of Macao; 2006.
[62] DSEC. Balance of energy. Macao, Statistics and Census Service of Macao; 2007.
[63] DSEC. Balance of energy. Macao, Statistics and Census Service of Macao; 2008.
[64] DSEC. Balance of energy. Macao, Statistics and Census Service of Macao; 2009.
[65] DSEC. Balance of energy. Macao, Statistics and Census Service of Macao; 2010.
[66] He PJ, Chen M, Yang N, Shao LM. GHG emissions from Chinese MSW incineration and their influencing factors-case study of one MSW incineration plant in Shanghai. China Environmental Science 2011;31:402–7. (In Chinese).
[67] DSEC. Yearbook of statistics. Macao, Statistics and Census Service of Macao; 2000.
[68] DSEC. Yearbook of statistics. Macao, Statistics and Census Service of Macao; 2001.
[69] DSEC. Yearbook of statistics. Macao, Statistics and Census Service of Macao; 2002.
[70] DSEC. Yearbook of statistics. Macao, Statistics and Census Service of Macao; 2003.
[71] DSEC. Yearbook of statistics. Macao, Statistics and Census Service of Macao; 2004.
[72] DSEC. Yearbook of statistics. Macao, Statistics and Census Service of Macao; 2005.
[73] DSEC. Yearbook of statistics. Macao, Statistics and Census Service of Macao; 2006.
[74] DSEC. Yearbook of statistics. Macao, Statistics and Census Service of Macao; 2007.
[75] DSEC. Yearbook of statistics. Macao, Statistics and Census Service of Macao; 2008.
[76] DSEC. Yearbook of statistics. Macao, Statistics and Census Service of Macao; 2009.
[77] Peters GP, Hertwich EG. CO_2 embodied in international trade with implications for global climate policy. Environmental Science & Technology 2008;42(5):1401–7.
[78] Wei YM, Liu LC, Wu G, Zou LL. Energy economics, CO_2 emissions in China. Beijing: Science Press; 2010.
[79] NDRC, the 12th Five-Year Plan. Beijing, National Development and Reform Committee of China; 2011.
[80] Peter G, Andrew L, Christine L. 'Green' house or greenhouse? Climate change and the building stock of Hongkong & Macau. Macao Architects Association of Macau 2008.
[81] Lai TM, To WM, Lo WC, Choy YS, Lam KH. The causal relationship between electricity consumption and economic growth in a gaming and tourism center, the case of Macao SAR, the People's Republic of China. Energy 2011;36:1134–42.